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Review

The Impact of Veterinary Medicine and Animal Husbandry on the Biophysical Characteristics of Soils in Neotropical Agroecosystems

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Abstract: The neotropical agroecosystems are important areas in the global scene in terms of livestock production. Therefore, a good conservation of their soils is crucial in order to both guarantee food safety and reduce the impact of land degradation processes. Conservation of neotropical soils used for farming activities could be obtained using veterinary medicine and adopting new grazing systems in the last decades. A wide bibliographical review was carried out which illustrates current issues in neotropical agroecosystems, the importance of their soil properties highlighting the role played by dung beetles within the edaphofauna, and the effects of the most common anti-parasitic practices as well as some natural alternatives. Finally, we present commonly adopted grazing systems and how they are affecting soil properties and animal welfare. The conversion of forest into agricultural and pasture land is altering the biochemical quality of soils. Furthermore, the use of ivermectin is dangerously reducing the total amount of dung beetles that are a key element in nutrient recycling processes. The implementation of new grazing systems (e.g., Voisin, Savory) is progressively fragmenting the habitat of many species. Nevertheless, there are also some benefits in this kind of practices and some natural alternatives to anthelmintics are being tested.

Keywords: soil properties; anti-parasitic; edaphofauna

1. Introduction

The 68th General Assembly of the United Nations (UN) agreed to declare 2015 to be the International Year of Soils recognizing therefore the soil as the source of a wide range of essential ecosystem services [1] that must be preserved for future generations. Under these circumstances, one of the most important challenges global society is currently facing is to be able to guarantee food security for feeding a growing population, estimated in 9 billion in 2050 [2] and keeping sustainable soil health conditions in the long term [3,4].

The increase in the number of people is also producing a higher global demand for animal products, particularly by those who belong to the so-called middle-class of society in developing countries [5]. Thanks to the emergence of new technologies and the widespread use of agricultural inputs, it might be possible to produce food for the world's total population, assuming provided distribution was equitable [6,7]. However, whether the long-term pressures on soils might be influenced by the increasing scarcity of land and other terrestrial resources is a persistent burning question [8,9].

Neotropical areas are one of the dominant regions in the global scene in terms of livestock production [10]. Morón and Schjtman [11] already showed a significant increase in the consumption of meat and animal products in the whole of Latin America, a trend continuously supported by Delgado et al. [12], Steinfeld et al. [13] and FAO (UN Food and Agriculture Organization) [14]. This increase in meat consumption, coupled with exports to other areas of the world that are also large consumers of meat [15,16] is causing a large amount of land to be allocated to livestock production [17,18]. The environmental consequences as a result of this increase in the numbers of animals and pasture land surface area are well documented [19,20].

Soil is a vital resource for food production, amongst many other valuable ecosystem services and functions it provides [21]. Its deterioration or loss could have serious consequences for mankind since it is not recoverable in the short term. According to FAO, it is estimated that it takes about 200 years to recover just 1 cm of fertile soil, which can be lost in a short rainfall event if the necessary precautions are not taken [22]. However, these values may vary regionally depending on weathering rates of rocks [23], or other soil formation factors such as climate, vegetation, topography or the activities of living organisms [24]. In neotropical areas, where the temperatures and the percentage of ambient humidity are usually high, any process of edaphogenesis, humidification and mineralization of soils occurs more quickly.

It is estimated that 95% of the food consumed by mankind is produced, directly or indirectly, by the soil [25]. Furthermore, the quality of food is highly related to the state of soil health [26]. A contaminated soil might add toxicity to everything that is grown on it, including the grasses that are naturally generated and this might provide additional negative effects on the ecosystem [20]. Within the scientific field of veterinary medicine, several studies show that the quality, taste and nutritive value of meat and even milk depend directly on the plants that the animals ingest [27]. A poor quality, or a soil that is being affected by degradation processes, finally reduces the production and the quality of the pastures and consequently negatively affect the whole system [28].

Despite the Green Revolution between the 1930s and the late 1960s, new movements and new ways of understanding the relationship between human beings and the environment have started to emerge since the 1970s. New scientific trends are aimed at the conservation of resources, including soil and the quest for sustainable practices, which cover the basic human needs and minimize their environmental impacts. Ever growing interest is also widespread, on the one hand, on the effects that climate change has on animal production and the overall sustainability of livestock farming systems across several agroecosystems [29] and on the other hand, on the impact livestock production has on climate change [30]. However, to date these practices are either few they have not been sufficiently disseminated or they require greater changes in the socio-economic and political contexts in which livestock farmers and land managers operate [31].

One of the most important problems farmers from neotropical areas have had to face is the control of parasites, which particularly proliferate in humid and hot environments such as the neotropics [32]. Since the decade of 1960s, the global tendency has been to find solutions for this problem in the advances of applied veterinary research through medicinal treatments (e.g., ivermectin) [33]. Its negative effects on animals (parasites resistance to medicine) and on the environment (toxicity in soil and water) were detected after a few decades of the use of ivermectin [34].

Taking into the account the abovementioned, this work is aimed at building a multidisciplinary bibliographic review with specific emphasis on the effects that certain veterinary and animal husbandry practices have on the biophysical quality of soils in fragile agroecosystems such as the neotropical ones. They are considered as fragile ecosystems because millions of hectares have been converted from neotropical forest into agricultural or pasture lands in the last decades and abandoned as well forming secondary forests [35]. as this is part of the philosophy of promoting soil conservation by FAO [36,37].

This work could serve as conceptual and empirical basis to propose strategies that allow minimizing the negative effects and enhancing those practices that maintain positive impacts, as well as suggest areas that require further research. The issues addressed in this article will also provide substantial information for the debate on the most efficient strategies for livestock management from the standpoint of soil properties.

2. Neotropical Agroecosystems

The currently used neotropical agroecosystems have a clear indigenous origin in which traditional crops and the breeding of native species followed a logical adaptation to the environmental limitation of each ecosystem [38]. As far as livestock is concerned, nomadic and semi-nomadic forms of livestock management and the increasingly dominant ranch management have coexisted for several centuries, following the gradual arrival of the European settlers since both the 15th century in America and 18th century in Australia. These forms of exploitation tended to maintain a balance between livestock and local pasture production, according to climate and soil varieties [39]. It is estimated that approximately one third of the rural areas of Latin America are currently used for extensive cattle farming [40].

According to Hanzen [41], neotropical agroecosystems have been a result of the past and present harvest of resources by countries in temperate zones more concerned about their productivity than their conservation, at least until 1970s. Some authors [42] stated that the most significant change in neotropical agriculture was due to the imperialism of Europe and the United States that converted natural habitats by logging and plantation in agricultural and pasture land. They supplied European and American markets with valuable products such as wood, sugar, tea, tobacco, coffee, meat and tropical fruits [43].

This commercial farming is also combined with an agroecological paradigm progressively practised in some farms. Agroecology promotes the use of renewable inputs and local or regional resources around the farms. These agroecosystems have survived for a long time in spite of suffering many social changes in land management throughout the history [44]. However, as an example, nowadays, the Mexican Service of Extensionism [45] suggests farmers adapt to the new trends of the global market because their sustainability of the ranches is now at risk.

Ruthenberg [39] classified seven types of farming systems in the tropics: (a) shifting cultivation, (b) semi-permanent cultivation, (c) systems with regulated ley farming, (d) systems with permanent cultivation on rain-fed land, (e) systems with arable irrigation farming, (f) systems with perennial crops and (g) grazing systems. Within the last one he also differentiated between total nomadism, semi-nomadism and ranching systems. The latter is a system in which animals are under greater veterinarian control.

A ranch (Figure 1) can be defined as a social productive unit that interacts with an agroecological and socioeconomic mean, involving natural, technical, human and cultural resources and producing valuable goods for self-consumption or for sale in local, regional or international markets [46]. In addition, Caparrós et al. [47] highlighted the provision of ecosystem services of ranches that should be incorporated in a wider definition.

Large ranches (>100 ha of land) where cattle is the dominant species coexist with smallholder livestock keepers, which represent 20% of the total population more specialized in the breeding of ruminants [48]. Most of the current pasture land has been obtained from the clearing of the neotropical forest. Repetto [49] estimated a rate of tens of thousands of square miles per year of deforested land in the neotropics.

The breeding of cattle (European and Indian breeds) has been traditionally an activity of great importance for local communities for the sale of both milk and meat [50]. Kurihara et al. [51] estimated almost 50% of the total cattle population (1.3 billion) is raised in the tropics. Furthermore, they considered tropical cattle as the main producer of methane released to the atmosphere. Other ruminants such as sheep and goats are also common in tropical areas, particularly sheep in the tropical areas of Australia [20]. Goats are particularly important in these ecosystems (15% of world's herbivores) due to the production of meat, milk and leather and their capacity of subsistence under more difficult conditions (e.g., droughts).

Figure 1. Illustrative picture of a herd of cattle (mainly *Bos indicus*) managed by a Voisin based rotational grazing system in a ranch in the south of Mexico (Yucatan Peninsula). Author: M. Pulido.

Cattle ranching in neotropical areas of Latin America have been characterized by the presence of an extensive monoculture of grass (e.g., Brachiaria brizantha [52]), not always well-adapted to local conditions and with frequent burns leading to serious problems of land degradation (soil and pastures) [53]. In addition, Perfecto and Vandermeer [42] considered that, regardless of deforestation, the main problem for tropical forests is their fragmentation.

3. Soil Properties

Soil is the most superficial layer of the Earth's crust in which most of the biological activity is concentrated. It originates from the weathering of rocks. It is composed of mineral and organic materials and based on its edaphic structure, it can store variable amounts of water and air [54]. On average, it is estimated that soil is composed of 45% mineral matter, 5% organic matter, 25% air and 25% water [55].

As a dynamic natural system, soil fulfils a number of key functions for human development [56], providing several ecosystem services [57]. It is the medium in which plants are established and grown, for example, food production, fibres, or medicinal plants, forage and biofuels. It regulates the cycles of carbon, oxygen and plant nutrients, that is, nutrient recycling. It absorbs and stores, purifies and releases water for water supply, that is, water reservoir [58]. It constitutes the largest reserve of terrestrial organic carbon, that is, carbon sinks. Soil is the habitat of animals, plants and organisms such as bacteria and fungi, that is, biodiversity; and soil is the support for almost all human activities.

As a result, soil quality, or soil health, is a concept or a variable that must be interpreted in terms of the degree or fulfilment of certain functions [59]. In livestock agroecosystems, everything must revolve around the function of food production, which is the soil's main function. However, in order to maximize this function, other functions must not be neglected. In fact, a good quality soil that produces a lot of fodder for animals in all likelihood will be a good soil storing water, recycling nutrients and even housing a great variety of edaphic fauna [60].

Consequently, soil degradation has to be interpreted as a negative process that is leading to a decrease in the quality of the soil, that is, to a worse performance of the key functions. Imeson [61] defines it as a deterioration of the resource, which causes a reduction of its biological potential and its productive capacity, encompassing many processes (natural and anthropic) and affecting both physical, chemical and biological properties. Soil degradation processes are usually triggered by some anthropogenic activity, as natural soil losses (geological rates) and their recovery by edaphogenesis tend to be in equilibrium in natural environments [62].

Stocking and Murnaghan [63] account for up to nine global soil degradation processes: (a) loss of vegetation cover, (b) water erosion, (c) wind erosion, (d) increased stoniness and surface rocketing, (e) soil sealing, (f) reduced fertility, (g) salinization and (h) decrease of the water table. FAO [36] remarks the spatial importance of other processes such as point and diffuse contamination, soil organic decline and loss of biodiversity. All these processes may appear separately or together, or even some processes may be cause or consequence of the others. Natural factors and some human activities can act as catalysts or shock absorbers of the mentioned processes. For example, steep slopes increase erosion rates while the construction of dams decreases the erosive power of water [64].

Globally, Oldeman [65] estimated that 33% of all the soils are moderately to highly degraded as a result of these processes. More specifically, some of the main problems faced by neotropical livestock agroecosystems are closely related to the lack of protection of the soil by means of vegetation cover due to the destruction of many hectares of forests to obtain larger pasture areas. This results in the appearance of spots of bare soil, which are eroded by the action of water and wind, leading to the visual appearance of a lot of rock surface and rocky outcrops [66]. This also causes a considerable reduction in contributions of organic matter by the remaining forest, which in the medium and long term reduces the water retention capacity of the soils [67].

Clear cutting practices also have a considerable influence on animal welfare [68]. On the one hand, there is a loss of areas of shade that allows livestock to take refuge from the heat or of protection to natural events like hurricanes [69]. In addition, clear cutting entails a loss of a source of food, since many shrub and arboreal species of tropical environments are palatable and nutritious for the domestic animals. Another factor to consider is the effect of these processes on climate change, as the potential of soils to act as organic carbon sinks would be noticeably reduced [70,71].

According to Van Bemmelen [72], most soil organic matter (58% of organic carbon) is concentrated in the arable layer (20–30 cm depth) [73]. Its role in the soil is vital, since together with the clay fraction it forms the so-called clay-humic complexes, which are the ones that enable the soil to generate an effective porosity, capable of retaining water, oxygen and nutrients and consequently maintain adequate conditions of fertility. An optimal content of organic matter also favours a greater fixation of nitrogen, although the latter presents certain limitations in calcareous neotropical environments [74].

The role that a healthy soil plays for biodiversity, especially regarding soil organisms, is a key question. It is estimated that in 1 m^3 of forest soil there may be more than 1000 species of invertebrates, millions of soil organisms such as worms, nematodes, mites, insects, microarthropods, fungi, bacteria, actinomycetes and so forth [75]. Among them, microfauna is responsible for the soil's biological activity and conditions that promote soil fertility [76]. For example, some methods for assessing soil biological quality, QBS by Parisi et al. [77], are based on assigning soil scores according to the microarthropods found in them.

A very important species for neotropical cattle farming is dung beetles (*Coleoptera scarabaeidae*), which play an important role in nutrient recycling and animal health. On the one hand, they reduce nitrogen losses and, on the other hand, act as a biological agent against nematodes and intestinal larvae that seriously damage animal health [78]. Rodríguez Vivas et al. [79] reported four major functions of beetles: (i) excreta incorporation, (ii) soil fertilization, (iii) fly control and (iv) control of gastrointestinal parasites.

4. Veterinary Medicine and Soil Quality

The improvement of animal performance and the related livestock farming productivity are two of the main goals traditionally pursued by veterinary medicine, as long as the practices do not endanger public health. Within these performance and productivity objectives, soil plays a key role as support for several livestock farming activities linked to the location of productive farms and the distribution and layout of pastures and corrals. Soil is also the main producer of fodder and livestock feed.

Over the past decades efforts to improve animal performance have focused in particular on the genetic side, on improving feed and inputs and increasingly with a concern for animal welfare [80].

As in many high temperature environments, native breeds or breeds that are adapted to heat (e.g., *Bos indicus*) are crossed with bulls of European breeds (*Bos taurus*) with greater weight gain performance with the aim of obtaining breeds well adapted to the environment and progressively gaining greater body weight [81]. The quest for animals with greater weight performance and needing shorter fattening periods has caused the generalization and mass production of inputs and much research on their efficiency, that is, cost/production analysis. The eradication, or reduction, of the negative effects of diseases, which reduce the fattening capacity of the animal, has also been addressed by veterinary medicine [82–86].

4.1. Most Common Anti-Parasitic Practices and Natural Alternatives

Animal production in neotropical environments is seriously affected by numerous threats, including the effects of parasites, which reach endemic levels [87,88]. The most common ones are gastrointestinal parasites, botflies and ticks, among several other species [89]. Their effects on animals are well known: loss of blood and protein, reduction in feed intake, anorexia and diarrhoea, among other diseases, which eventually end up reducing production of meat or milk and eggs in the case of poultry [90].

For many years, the solution that veterinary medicine has provided for the control of parasites has been the use of anthelmintics such as ivermectin (macrocyclic lactones) and its derivatives. However, some studies have already reported the occurrence of gastrointestinal nematode genera resistant to ivermectin [91] and harmful effects of its use on the abundance and diversity of beetles, which act as natural pesticides against this type of parasites [92].

To avoid higher medicinal costs for farmers and to avoid further negative environmental impacts, many experts advocate for an individualized examination of the animals, identifying those who truly need the use of deworming agents. One of the most used methods, especially in small ruminants, is the FAMACHA method [93], that allows to differentiate animals by the colour of the conjunctiva of the eye, discerning between those animals that must be dewormed and those that do not need treatment.

Other lines of research being developed seek the solution to parasite problems using more natural means. The role played by beetles in reducing gastrointestinal parasite eggs (HPG) further supports the positive results already obtained with neem leaves (*Azadirachta A. Juss iltdica*) [94] and foods rich in tannins [95]. However, these beetles are increasingly threatened by the destruction of many hectares of forest [96] and, ironically, also by the widespread use of ivermectin itself [97].

The potential impacts of natural practices on soils are still unknown while there is clear evidence of deterioration that medicinal products used in veterinary medicine exert on the quality of soils in tropical and subtropical regions. The reduction in size of beetle populations due to the use of ivermectin implies a clear regression in the nutrient recycling function and, consequently, in the improvement of soils and pastures. The cost to ranch owners in the United States as a result of the disappearance or decline in the population of beetles was an estimated 380 million dollars.

The main medicinal products used for animal health control, such as deworming and antibiotics, eventually end up in the soil through the animals' excreta, that is, faeces and urine [98]. According to Kromp [99], these types of products reduce or make disappear populations of coprophagous beetles responsible for burying manure and other species, which are key to gas exchange and soil respiration, whilst they facilitate the population surge and resistance of flies harmful to livestock and humans.

4.2. Grazing Systems for Disease Prevention and Animal Welfare

Another aim pursued by veterinary medicine and animal husbandry, in collaboration with different scientific branches of agronomy, is to seek optimal utilization of pastures and grazing management strategies, which allow the animal to feed properly and provide both in the soil as in pastures, adequate sanitation conditions that ensure the sustainability of the system [100–103]. Grazing systems should be designed to get the most out of the environment without deteriorating it.

They should be adapted to the climate as well as to topographic and edaphic conditions and take into consideration the socio-economic and cultural aspects of livestock farming.

Since the end of 1990s, in many neotropical agroecosystems, perhaps motivated by a greater need for food production worldwide [104], farming tended to favour monoculture of grasses to the detriment of a considerable fraction of tree cover [105]. This fact had negative consequences for the animals themselves and also for the soils. By reducing shaded areas, animals suffer from heat stress and lose one of their main food sources, the branches and the leaves of the trees, which are crucial to their survival in a natural way without inputs during the dry seasons.

The reduction of tree cover mainly affects two aspects. On the one hand, through the loss of biological activity of the soils, it reduces the activity of microorganisms, especially of coleopteran beetles and the contribution of organic matter of vegetation remains, with consequent impacts on soil structure. On the other hand, the lack of protection leaves the soil surface exposed, particularly in the dry seasons, which results in greater losses due to erosion during the first rainy events. This is evidenced with a greater stoniness and rockiness on the surface and in the case of clay rich soils, in the visual presence of cracks of desiccation and with increasing probability of greater compaction, and even watering problems likely related to a decrease in water retention capacity of the soil.

Other practices that affect soil quality and which have been or are being frequently adopted in some neotropical areas are the use of fire, for example, tillage, slash and burn systems; the intrusion of crops (not always fodder); and an increasingly intensive use of livestock. Although herbaceous production in neotropical areas is relatively high and rapid and even owners consider that they are not taking advantage of all the forage that grows on their land, grazing systems must be designed based on the livestock carrying capacity of the land. Therefore, criteria for the design of such systems should consider the size of grazing plots and pastures, animal performance and they should allow adequate resting times during which the land is not grazed.

A generalized dynamic, not only in neotropical environments, motivated by many different factors, is the passage from an open or free (continuous) grazing, where the animal can graze in tens or hundreds of hectares without finding a barrier, to a more restrictive and controlled (rotational) grazing, in which ranches subdivide land surface areas in an ever-greater number of sub-plots using movable or fixed fences. Evidence of this fragmentation of the landscape of cattle ranches has been reported by Lavado Contador et al. [106] in the Spanish "*dehesas*" and by Antoneli et al. [107] in the "*faxinais*" of the south of Brazil.

In neotropical areas, published works have tested the effects of implementing grazing systems with a greater number of pastures or with a resting period (deferred) [108,109]. Voisin [110] proposed a new rotational grazing system, which is considered by many to be the most efficient pasture-based grazing system. Savory [111] developed a rotational system of short duration and high frequency of grazing, although the author did not find great differences compared to the system of continuous management, except in times of scarcity. Jones [108] reported a large benefit in the seed bank with the practice of deferred grazing.

In spite of the enormous literature on grazing systems and recent work on high intensity rotational grazing systems derived by Voisin's and Savory's initial work, very few studies have dealt with the specific effects that these systems have on soils in neotropical areas. Consequently, they serve conclusively to recommend which system is ideal for the preservation of the quality of the soils. One of the most complete works, in this sense, was the one published by Humphreys [112], which addresses the problems of compaction, erosion and fixation of nutrients such as nitrogen, the latter as direct or indirect consequences of defoliation, in addition to changes in botanical composition, in tropical areas of Australia [20].

5. Conclusions and Recommendations

There is clear evidence of the negative effects of chemicals used in veterinary medicine on the health of soils in neotropical regions. There are natural alternative products (e.g., neem leaves) that could be incorporated into animal production systems in neotropical agroecosystems but this does not happen for several reasons, primarily related to lack of knowledge or lack of technological development in spite of the wide availability of natural products. Further research needs to be carried out about the implementation of more sustainable livestock practices that reduce the impact of residues from veterinary interventions, as well as strategies to overcome barriers to their adoption.

Regarding worrying trends in land degradation processes such as soil compaction and erosion, these are mainly a consequence of an increasingly deforestation process of the neotropical forests in order to obtain more land surface of pastures. This significant reduction in the number of trees is consequently causing the depletion of sources of soil organic matter (e.g., tree litter fall), the removal of the vegetation cover protection, and problems of soil compaction through the destruction of soil structure by animal trampling.

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